A Comparative Analysis of an Alternative Synthetic Blend Refrigerant to Its Predecessor: NU-22 vs HCFC-22

An Honors Thesis (HONRS 499)

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Abstract

The need has presented itself to turn away from the currently used chlorofluorocarbons, or CFCs, that have proven extremely detrimental to the Earth's environment, and move toward a new form of refrigerant technology. From disastrous ozone depletion creating holes in the protective layer that surrounds the globe, to the effects of greenhouse gases that contribute to the major issue of global warming, time is of the essence in preventing further atrophy in our ecosystem.

In response to the current void in refrigerant replacement technology, a new provider in hydrofluorocarbon synthetic blends has risen to the challenge of producing the first and only direct replacement for the widely used refrigerant R-22, also known as HCFC-22. ICOR International lays claim to this "drop in" refrigerant blend that does not need retrofitting or lubricant change within the refrigeration unit itself. ICOR boasts that this replacement, called NU-22, is a practical, safe, efficient, versatile, and effective substitute for R-22.

Muncie has been home to the local business City Ice & Cold Storage Company for over 100 years who currently use R-22 in their ice producing machines and refrigeration cabinets. Management is concerned with the impact a replacement refrigerant would have on their production, energy consumption, and machine stability. These and other factors would ultimately affect cost in switching over to a more environmentally safe option. Because of government mandating a reduction in HCFC consumption, it is a realistic probability that City Ice must find an alternative to R-22 within the next 20 years.

Research has been conducted to determine if NU-22 could be a viable option for the refrigerant needs of the business in the present and for the future. In a real world application, NU-22 was charged into machinery and monitored over a period of time to determine how it performed in comparison to the standard, R-22. A battery of tests was conducted to determine temperatures, pressures, voltage, and amperage measurements that all can be used to either justify or disprove the claims made by ICOR International. Results and conclusions based on the information gathered from these experiments are outlined in detail through discussion of different variables, graphs, charts, and data tables.

Introduction

The need has surfaced for alternate refrigeration technology to replace the harmful and dangerous effects that currently plague the use of HCFCs, hydrochlorofluorocarbon, as refrigerants. Ecological factors such as ozone depletion and the greenhouse effect have brought about awareness of the damaging effects that certain refrigerants have on the Earth's atmosphere. HCFCs are used extensively in the refrigeration and air conditioning industries with HCFC-22 being the most common. Its composition is that of a CFC, chlorofluorocarbon, with an additional hydrogen attached, making its molecular formula $CHClF_2$, chlorodifluoromethane. It is because of the additional hydrogen that the compound experiences less stability in lower atmospheres increasing its ability to breakdown more readily before reaching the ozone layer. Even though HCFCs are substantially less harmful to the environment than their CFC predecessor, they are still capable of further damaging layers of ozone, O_3, if their usage is not drastically reduced in a timely manner.

The Montreal Protocol on Substances that Deplete the Ozone Layer is an international treaty drafted and opened for signature on September 16, 1987. The treaty's principle design is to protect the ozone layer from depletion by phasing out a number of detrimental substances thought to contribute to the problem. A timetable was presented by the treaty for each group of halogenated hydrocarbons, including HCFC-22, which called for phasing out production with the ultimate goal of eventual product elimination. Further provisions of the protocol state that the participating parties must base all future decisions on currently available scientific, environmental, technical, and economic information assessed through panels of worldwide expert communities. Largely hailed by many as "perhaps the single most successful international agreement to date" the treaty has now been adopted by 183 different countries worldwide.

Initially created to phase out CFCs and comply with the Montreal Protocol, the United States Congress passed the 1990 Clean Air Act that ordered the Environmental Protection Agency, EPA, to enact regulations against all ozone-depleting chemicals. Although this is a federal Act that encompasses the entire country, much of the work is actually carried out on a state level. The EPA is responsible for setting the guidelines that each state must follow and uphold through hearings on permit applications and fines for policy violations. This law allows for states to have stricter control over regulations, but not weaker than those set by federal standards. There was a recorded decrease in HCFC consumption of approximately 9% between 2001 and 2002.Unfortunately Indiana is currently 8^{th} among those states leading in amounts of HCFC-22 released annually according to recent statistics totaling a sum of approximately 273,000 pounds released each year.

In January of 2003 the EPA published a regulation that limited the amount of virgin R-22, also known as HCFC-22, that can be made or imported into the United States. Prior to this time any company could make, import, or sell the refrigerant. This new regulation only granted twenty-five companies to have limited rights to manufacture or import R-22 for use in systems that would ultimately release the chemical into the environment. This regulation not only covers the 50 U.S. states, but also territories and provinces such as Puerto Rico, Guam, and the U.S. Virgin Islands. This 2003 action by the EPA allowed the United States to meet the 35% reduction in HCFC consumption required in 2004.

Further regulatory measures are being taken both in the present and the near future to significantly reduce HCFC production. The 2004 Beijing Amendment Ratification to the Montreal Protocol has lead to the EPA's ban on buying and selling of controlled HCFCs with certain countries. This amendment requires countries who manufacture HCFCs to agree to limit the amounts of chemicals they produce. China and Mexico are two countries on the list that represent a substantial amount of imported R-22 to the United States. in recent years. Due to the Department of Energy regulations passed in 2002, the minimum efficiency of most new residential air conditioners is being raised in 2006, which will effectively require air-conditioning manufacturers to use 15%-25% more R-22 refrigerant in new equipment, thus increasing its demand. The R-22 allocations originally granted by the EPA will expire in 2009 with no further regulations in place that would allow for R-22 to be made or imported after 2009. The EPA is also required to implement additional regulations to reduce and limit the consumption of ozone-depleting HCFCs by 90% after 2014, 99.5% reduction by 2020, and ultimately the complete phasing out of HCFC production by 2030.

To fully comprehend the severity of the problems that require such legislations it is important to understand the nature and the chemistry behind it all. Chlorodiflouromethane, HCFC-22, is a non-flammable, colorless, and nearly odorless gas under normal conditions. Although there are no universally recognized health hazards identified with $CHClF_2$, it is suspected that R-22 possesses the potential to be a cardiovascular or blood toxicant, endocrine toxicant, developmental toxicant, kidney toxicant, respiratory toxicant, and neurotoxicant. This HCFC has moderate water solubility and low octanol/water partition coefficient that indicates a negligible bioaccumulation potential. Water and food contamination are not expected. The calculated Ozone Depletion Potential, ODP, is therefore low, being only about 0.045 compared to that of 1.0 for fully halogenated CFCs like trichlorofluoromethane and dichlorodifluoromethane. Most of the R-22 released into the atmosphere is destroyed by a reaction with naturally occurring hydroxyl radicals, OH, in the troposphere. OH and oxygen atoms in their excited state can typically destroy that portion which reaches the stratosphere, but not to a major extent by photodecomposition. CFCs primarily break down in the upper atmosphere, which can break down the protective ozone layer by releasing atomic chlorine, Cl. HCFCs also release their chlorines, which has contributed to a greater chlorine buildup in the upper atmosphere than was once originally projected..

The nomenclature used for identifying the composition of a refrigerant is determined in the following fashion using R-22 as an example:

1) Add 90 to the CFC/HCFC number to give a 3 digit value *R-22*: **22+90 = 112**

2a) the leftmost digit is now the number of carbon atoms, *R-22*: **1 C**

2b) the middle digit is the number of hydrogen atoms, *R-22*: **1 H**

2c) the rightmost digit is the number of fluorine atoms *R-22*: **2 F**

3) all remaining atoms are chlorine *R-22*: **1 Cl**

H
|
F - C - Cl
|
F

Ozone depletion can be characterized through a series of reactions that were first published in a paper by Sherry Rowland and Mario Molina in 1974. Unreactivity, one of the CFCs greatest strengths for effective refrigeration, is unfortunately also its greatest weakness. This unreactivity makes it one of the most significant and enduring pollutants. Some CFCs can remain in the atmosphere for a lifetime of over 100 years, whereas

HCFC-22 averages about 11.9 years. Even if the release of CFC and HCFC chemicals were to cease this instant, their damaging impact would continue to reduce the ozone layer's efficiency for countless years to come. Given this span of time, the harmful chemicals can diffuse to the upper stratosphere where they are subjected to the sun's ultraviolet radiation. This radiation is strong enough to break the highly reactive free radical chlorine atom from its compound which subsequently catalyses the break up of ozone into oxygen in the following reaction:

$$Cl + O_3 \rightarrow ClO + O_2$$

$$ClO + O \rightarrow Cl + O_2$$

The chlorine is regenerated at the end of each reaction, which poses the unique threat of being capable of repeating this process millions of times. This reaction disrupts the ionic structure of oxygen and causes their lowest ionization energy to drop. The consequence of these reactions is believed to be the main contributor to holes in the ozone layer observed over the upper poles and latitudes of the Earth. These holes have been directly linked to increased cases of skin cancer and the rise in average seasonal temperatures around the globe.

Jean Baptiste Fourier discovered the traditional concept of the greenhouse effect in 1824, by theorizing the manner in which an atmosphere warms a planet. A different connotation has surfaced in recent decades as the term "greenhouse effect" has expanded to a separate definition now based on anthropogenic greenhouse effect resulting from human activity. A long debated topic among the scientific community, the enhanced greenhouse effect has resulted from the ecological distress caused from increases in pollutants such as CO_2, SO_3, CO, CFCs, and other chemicals combined with the destruction of naturally detoxifying vegetation, for example, the vast forests getting wiped out due to over logging. Along with a possible increase in solar activity, these factors have lead to the idea of global warming. Global warming encompasses the belief that over time, the Earth is experiencing an alarming increase in its average atmospheric and oceanic temperatures. The refrigerant R-22 is widely considered a minor greenhouse gas that actively contributes to the environmental distress. A ranking system of Global Warming Potential, GWP, was developed to convey the relative danger of each man made chemical contributor to global warming. With a baseline comparison against CO_2, with a value of 1.0, R-22 currently holds the observed GWP value of 1,700.

Now that the wide variety of dangers connected with HCFC consumption are better detailed and understood, it is important to be aware of developments in safer alternative methods of replacement refrigeration technology. The world's first refrigerant ammonia, NH_3, was replaced in 1928 by American engineer Thomas Midgley after its corrosive and toxic nature was deemed too hazardous for common usage. Midgley developed CCl_2F_2 , CFC-12 or Freon as it is commonly known, as a great alternative because of its low boiling point, non-toxicity, and non-reactivity. Work on CFC alternatives started in the late 1970s after initial findings about potential damaging affects to the stratospheric ozone were discovered. This led to the addition of hydrogen into the compound, and the creation of HCFCs. The elimination of CFC production in developed countries commenced on December 31, 1995. Now the time has arrived to find the heir to the next generation of refrigerants that will be safer for the environment, while being effective and cost efficient for consumers.

For the last two decades the focus has been on the development of new synthetics and blends, and recycling the HCFCs still in use. The EPA set modest goals in recovery of the refrigerant through a mandated reclamation of HCFC-22 in service operations within the United States. 7.1 million pounds of R-22 was reclaimed during 2000, but in prospective this only accounted for less than 3% of the annual allotment set by the EPA for U.S. consumption. In the near future, reclamation of R-22 is unlikely to significantly fill the market demand for a service refrigerant unless recovery efforts substantially increase. The ideal solution to HCFC replacement would be to design a "drop in" replacement where no oil change is necessary in replacing the R-22. Currently replacement of HCFCs in a system usually requires some or all of the mineral oil to be replaced with a lubricant more compatible with the structure of HFCs that lack chlorine. Without such an appropriate lubricant, the result can be a decrease seen in the rate of oil return to the compressor in the system, potentially to the point of compressor burnout or early failure, thereby reducing the long-term reliability of the system. Use of these "drop ins" can invalidate warranties on new or replacement equipment, significantly reducing the market for such technology. These HFC alternatives are also accused of having lower efficiency and capacity than R-22, which could result in slowed production or unpredictable temperature variations.

However, with time this alternate avenue has been constantly improving with several viable candidates coming to the forefront in mainstream replacement. One such compound produced by ICOR International is boasted to be "the first and only direct replacement for HCFC-22" as a refrigerant blend with zero ODP given the name NU-22.

The chemical composition is a blend of three components:

Pentafluoroethane CHF_2CF_4 HFC-125

```
    F   F
    |   |
F - C - C - H
    |   |
    F   F
```

Tetrafluoroethane CF_3CH_2F HFC-134a

```
    H   F
    |   |
H - C - C - F
    |   |
    F   F
```

n-Butane C_4H_{10}

```
    H   H   H   H
    |   |   |   |
H - C - C - C - C - H
    |   |   |   |
    H   H   H   H
```

Pentafluoroethane is a non-flammable colorless gas that degrades in the atmosphere to CO_2 and HF through reactions with naturally occurring hydroxyl radicals. Although this component of NU-22 has no effect on stratospheric ozone since it contains neither Cl nor Br, it has an atmospheric lifetime estimated to be nearly 41 years. Tetrafluoroethane is also a non-flammable, colorless gas, but with a faint ethereal odor. Butane is a colorless alkane that is extremely stable, experiences no corrosive interactions with metals, is slightly soluble in water, and readily soluble in alcohol, ether, and chloroform.

The comparison between NU-22 and R-22 invokes many important similarities that prove both beneficial and detrimental in terms of finding the next major refrigerant. R-22 has a larger range of temperature usage by nearly 10 ^{o}F and is a less bulky molecule having a molecular weight of 86.5 g/mol compared to 106.6 g/mol of NU-22. R-22 also has the capability to withstand a much higher critical pressure, 170 psi more than NU-22. One important factor that is universally accepted is that NU-22 and similar replacements do act as greenhouse gases. It is almost like choosing the lesser of two evils in replacement technology as NU-22 has a higher GWP than R-22, 1,950 compared to 1,700, even though its ODP is considered negligible.

To either confirm or disprove manufacturer claims by ICOR of practicality, versatility, compatibility, and efficiency is the goal of the qualitative tests conducted through the course of this independent experiment.

Experiment

During the experiment planning process, it was determined what factors would be most informative in relaying comparable standards of practicality, versatility, compatibility, and efficiency in regard to important key variables that may influence results in a multitude of ways. It was decided to measure the data gathered in terms of the temperature drop experienced through the cooling process including the minimum temperature reached in the associated time frame, thus determining an accurate cooling rate for each system. Pressure is also a main factor measured in the experiment because it can accurately detail how the system is integrating the new refrigerant and how well it is able to adapt. To gauge cost effectiveness, it is crucial to get an idea of the maximum, minimum, and average voltages and amperages experienced in an average refrigeration cycle to forecast future financial involvement.

Variables for each of these tested factors exist and must be confronted to allow for the most accurate results given the nature of this real-life application experiment. My qualitative analysis is vital to understanding the true nature of using NU-22 since the experiment takes place in the field, outside of the controlled laboratory setting used in ICOR International's manufacturing tests. The variable most important in measuring temperature in this scenario is the control of ambient temperature, or the surrounding air temperature outside of the system. If this variable were allowed to differ significantly between experimental trials the temperature inside the cabinet would be different enough to hinder the cooling rate comparison. Additionally, the heat exchange that takes place within the refrigeration cycle could be influenced by the immediate surroundings, effectively altering efficiency determination.

Variables associated with the pressure measurements could be slightly influenced by atmospheric pressure although it was not practical to control this dynamic due to its minimal differentiation throughout the course of experimentation as found relatively consistent during the course of the experimentation process. Another consideration was that practical application would require changes in atmospheric pressure incorporated into the design of the experiment to help in determining the versatility of NU-22. Another variable addressed concerning both temperature and pressure was the point in which each measurement was taken within the refrigeration cycle. To account for this, measurements were taken on both the "low-side" and "high side" which correlates to the points in the refrigeration cycle where the gaseous refrigerant begins the initiation of the cycle and where it is returned in a liquid form to be utilized again after completion of its cooling task. To better understand this concept it helps to be familiar with the gas laws including the ideal gas equation, $PV = nRT$, which relates pressure and volume to constants and temperature crucial to the basics of refrigeration.

The refrigeration cycle can be understood as a closed circuit involving a compressor, condenser, expansion valve, and suction line. The basic idea involves the endothermic process that absorbs heat and allows the refrigerant to evaporate into a gaseous vapor, cooling the desired area of the circuit. The refrigerant then carries this heat throughout the circuit until it undergoes an exothermic reaction when compressed back into a liquid, releasing heat into the surroundings. The high-pressure liquid enters the thermostatic expansion valve, and is converted to a low-pressure vapor within the suction line where the liquid evaporates to carry heat from the inside of the cabinet to the outside. The vapor travels to the compressor where it becomes a liquid under high pressure, releasing more heat into the environment. By continuing through the condenser the refrigerant cools and drops in pressure to be used in the cycle again.

Experimental design was crucial to the plan prior to any calculations or data collection. A test freezer, also known in the industry as an ice merchandiser, was selected to conduct the experiments. The merchandiser was chosen as an ideal test subject, a newly purchased Leer Model 65 ice freezer and currently running on R-22.

The 65 ft^3 cabinet designed to hold bagged ice at a freezing temperature in an outdoor setting was idyllic in continuing with the hopes of maintaining the goals of practicality of equipment usage in this real-life experimental trial. The cabinet was equipped with a Tecumseh 1/3 horsepower low-temperature condensing unit, which is a cap-2 non-receiver unit. Since this unit had never been used, it contained a full charge of R-22 upon our first trials. The diagnostic equipment chosen for the experiment was a combination of Logitech data loggers specifically designed to measure duel variables. The logger used to measure temperature and pressure simultaneously, and the one used to measure voltage and amperage likewise were attached separately to a Hewlett Packard Pavilion N3250 laptop computer.

The timetable designed to maximize experimental results factored in many important aspects to ensure useful data. Initially, it was important to measure the baseline characteristics of the unit using R-22 since it was already charged into the system. The decision to do this was based on prevention of possible experimental error due to switching of refrigerants in the opening steps of the experiment. Once this vital information was gathered to provide a consistent comparison to the unknown characteristics of the replacement refrigerant, the R-22 was completely discharged and captured from the refrigeration unit. NU-22 was then charged into the system in a commensurate amount to that of the previously present R-22. The diagnostic equipment then gathered the initial data of NU-22's performance in the refrigeration cycle. As this data was being interpreted, the decision was made to place the ice freezer into service in a real world application. The merchandiser was set at Aramark catering services on the grounds of the popular concert venue Verizon Wireless Music Center in Noblesville, Indiana, throughout the entire summer of 2003. Once retrieved, at the end of September 2003, the unit was again connected to the diagnostic equipment to judge the impact of NU-22 on a machine that experienced consistent and practical daily use in an outdoor environment. The unit underwent conditions such as being outside in a variety of outdoor weather situations such as varying daily and evening temperatures, humidity, direct sunlight, and precipitation. Additionally it experienced constant opening and closing of the door to retrieve bags of ice, thus changing the cabinet temperature in an unpredictable manner. Each of the variables was tested repeatedly to ensure that reproducibility was among the factors tested for in providing an optimal amount of accuracy.

Analysis, Results, & Discussion

The initial experimental results yielded useful information specifically tested for in characterizing each aspect of both R-22 and NU-22. It was determined after the experimentation process that indeed reliable data had been generated, producing congruent results used in comparing practicality, versatility, compatibility, and efficiency between the two refrigerants. In the following discussion, several factors within the results will be specifically addressed to provide insight into the overall purpose and details that will be monitored in the next phase of testing.

Quite possibly the most important comparison factor tested with the potential to ultimately lead to a quick dismissal of the new technology is the ability of NU-22 to be compatible within a R-22 system using the original mineral based oils. At the risk of negating limited machinery warranties, this crucial element of the results was highly considered at length. Using evidence based on pressure and temperature stability, and noticing how the system responded on the short-term basis of our initial testing, it was found that there is not a significant immediate risk to machinery charged with the replacement refrigerant. However, there are factors that could contribute to the long-term functioning of an ice merchandiser that must be monitored in the next battery of tests. Most alarming of these would be the results of pressure readings on the high-side of the NU-22 circuit. The extremely high-pressure of over 240 psi, detailed in **Data Sheet 1**, persisted for nearly 30% of the entire trial. Although adding noticeable strain on the start-up of the system, this pressure eventually stabilized, effectively reducing potential problems that could, in the long-run of multiple start-ups, damage the compressor. No evidence suggested non-compatibility of the lubricant based on observations of machinery function, which encountered little significant mechanical distress different from that of the R-22 system.

To determine the efficiency of NU-22 qualitative analysis was done to the data to derive trends from the comparative testing. Amperage draw and voltage readings did little to support any increased efficiency claims over the standard R-22. The difference in maximum amperage draw was found to be + 0.5 Amps by NU-22, as detailed on **Data Sheet 1**. Although being higher by + 0.4 Amps, the minimum amperage draw experienced by the R-22 proved more constant and steady, only differing at most by 1.2 Amps between peak and trough. Contrarily, the amperage draw by NU-22 was found to be more erratic, differing by up to 2.1 Amps through the duration of the 3 hour long experiment, almost doubling the average difference found in R-22 results. A similar distinction was observed in the voltage of the circuit as the R-22 peaked at 3.0 V and troughed at 2.4 V, varying only by a mere 0.6 V. NU-22, however, differed a full 1.0 V as it experienced a maximum of 5.1 V and a minimum actually higher than the maximum found of R-22. These results clearly indicate a high potential of energy consumption of NU-22 in real-world applications. The next wave of experiments will give insight to the longer-term effects of NU-22 in terms of efficiency and overall realistic potential cost.

Another important factor, cooling rate, also produced results that favor R-22 in many ways. The rate at which the system inside the cabinet was cooled proved to be much faster for R-22, reaching a lower temperature than NU-22 in a shorter period of time by over 20%. The graphs of the low-side comparison of the system yielded the information used in the cooling rate relationship. The overall cooling rate efficiency was calculated to be –0.361 °F/ minute for R-22 and –0.288 °F/ minute for NU-22. High-side measurements taken within the actual circuit of the refrigerant showed relatively high measurements for both refrigerants. Based on this information it was decided to incorporate cabinet testing of temperature for both high-side and low-side testing in the next wave of experiments since the overall trend of the high-side calculations yielded relatively little helpful variation in high-side temperature after initial startup of either system. It is noteworthy, however, that the results from high-side temperature testing for the NU-22 displayed a significantly higher temperature to the point of 27-33% more than R-22. This is congruent with the voltage and amperage measurements indicating a much higher amount of energy being utilized in releasing the heat into the surroundings causing a higher amperage and voltage usage and revealing the lack of efficiency of NU-22.

Some initial observations suggest that NU-22 is certainly not a more efficient choice, and has some potential of compatibility issues if the pressure does not reduce in the beginning of the high-side circuit in the future trials. Versatility and practicality will be revealed after the NU-22 charged freezer has been retrieved from its tour of duty at Verizon Wireless Music Center. The actual graphs used as a basis for the analysis of data gathered can be found in the **2003 R-22 & NU-22** graphs section.

The second phase of the research was initiated a full calendar year after the test unit was placed in the field to be used on a regular basis. Once the ice merchandiser was returned to the factory it was hooked up to the diagnostic equipment to collect data used to determine how NU-22 was integrated into the system and how the unit reacted to such prolonged use. Since the baseline R-22 data provided from the first set of tests proved relatively valid in comparison to actual data universally accepted for the HCFC, no need to re-charge the system presented itself. In fact, by not altering the composition within the refrigeration cycle more reliable data has been gathered due to a reduction of experimental error stemming from less modification. Rather, two trials were done using the NU-22 charged system in hopes of providing reproducibility among the results.

Many interesting results were gathered during this second phase of data collection. In following up on data results from the initial testing, several key inferences can be made relating to the consistent data. Throughout the course of time in the field, the test unit appeared to have incorporated the new refrigerant into its system in a way that made the data further congruent with itself. Reproducibility indicates a high level of accuracy in the most current findings. Measurements appear to be more settled and consistent than the more erratic nature previously observed.

Key observations regarding the new data include more accurate trends in pressure and cooling rate, as well as more precise voltage and amperage measurements. **Data Sheet 2** provides calculations and results of the second battery of tests that express these trends in more detail. The area of highest concern regarding maximum pressure encountered on the high-side of the system showed an eventual leveling off to a less harmful pressure. Despite having an average high-side pressure greater than the maximum of R-22, NU-22 displayed a decrease of 53 psi overall since the previous test that places it in a much safer region of use. The new findings produced measurements of 188.5 and 188.2 psi encountered upon start-up of the system, nearly 22% less than it was measured to be in the first trial. This places the R-22 alternative in a much safer range of pressure that would certainly have less negative impact on the machinery in the long term. Regardless of this improvement, directly compared to the highly efficient and uncreative nature of R-22, the synthetic blend cannot match its predecessor's innate strengths.

In judging the results of the amperage and voltage comparisons, as well as the cooling rate, it can be observed that the trend toward more reliable data collection has continued as it had for pressure calculations once the system has been in use for a prolonged period of time. A 5 % reduction on average amperage draw observed from these new tests suggests that our initial tests were very accurate with a low experimental error only evident from precise results. This further supports the results of efficiency determination present from previous testing, indicating little change from the original data. Voltage determinations proved to be different from those initially determined. As with the other values, voltage appeared to stabilize and produce more consistent data after being integrated into the system. Only a 0.7 V separation was noticed from maximum to minimum values, which results in a 30% less erratic range experienced throughout the experimental process. The overall maximum and minimum also dropped in value of 1.3 – 1.0 V respectively, placing these values much closer to those observed in the R-22 trials. Although improvement is noted, the overall results indicate R-22 draws less voltage on average of about 0.7 V, but less amperage averaging about 1.0 Amps per cycle. The overall average cooling rate experienced some improvement as well increasing by nearly 3%, from – 0.288 to –0.316 °F / minute, but still falling short of R-22, -0.361 °F / minute, by over 12%.

Data Sheet 1: R-22 & NU-22(2003)

Ambient T: 68.0 °F	R-22	NU-22
Maximum Low-side T:	58.80 °F	54.82 °F
Minimum Low-side T:	-6.67 °F	2.59 °F
Maximum Low-side P:	27.30 psi	58.60 psi
Minimum Low-side P:	4.10 psi	2.70 psi
Average P:	8.18 psi	8.50 psi
Maximum High-side T:	83.55 °F	114.60 °F
Minimum High-side T:	52.99 °F	79.38 °F
Maximum High-side P:	150.80 psi	241.50 psi
Minimum High-side P:	101.80 psi	124.20 psi
Average P:	105.73 psi	131.995 psi
Maximum A:	8.10 Amps	8.60 Amps
Minimum A:	6.90 Amps	6.50 Amps
Average A:	7.25 Amps	6.97 Amps
Maximum V:	3.0 V	5.10 V
Minimum V:	2.40 V	4.10 V
Average V:	2.71 V	4.46 V
Overall Average Cooling Rate:	**-0.3610 °F / minute**	**-0.2880 °F / minute**

Key: T – temperature(°F) P – pressure(psi) A - Amperage(Amps) V – Voltage (Volts)

Data Sheet 2: NU-22 (2004)

Ambient T:	71.0 °F	70.0 °F
Maximum Low-side T:	69.39 °F	62.95 °F
Minimum Low-side T:	11.67 °F	6.48 °F
Maximum Low-side P:	85.40 psi	71.50 psi
Minimum Low-side P:	11.70 psi	10.80 psi
Average P:	13.37 psi	13.85 psi
Ambient T:	69.0 °F	70.0 °F
Maximum High-side T:	64.18 °F	63.36 °F
Minimum High-side T:	7.08 °F	7.22 °F
Maximum High-side P:	188.50 psi	188.20 psi
Minimum High-side P:	144.60 psi	140.30 psi
Average P:	151.06 psi	155.31 psi

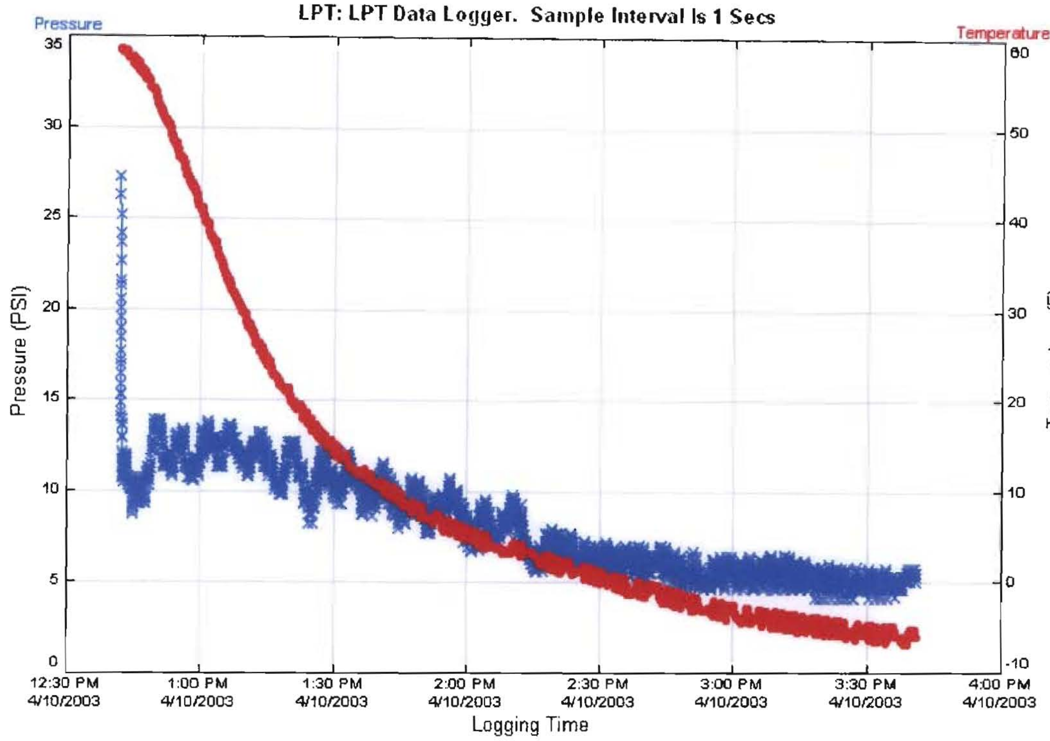
Maximum A:	8.10 Amps
Minimum A:	6.10 Amps
Average A:	6.59 Amps
Maximum V:	3.80 V
Minimum V:	3.10 V
Average V:	3.44 V

Overall Average Cooling Rate: **- 0.315873 °F / minute**

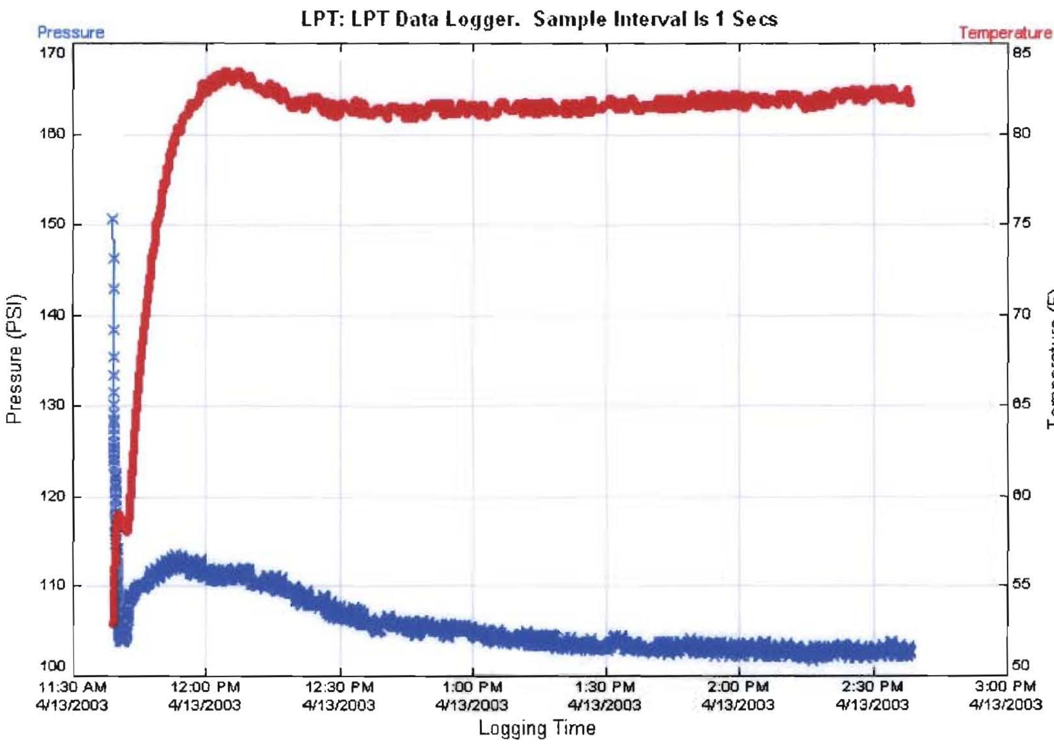
Key: T – temperature(in °F) P – pressure(in psi) A - Amperage(in Amps) V – Voltage (in Volts)

2003 R-22 & NU-22 Graphs

R-22 Low-side
(ambient: 68 °F)

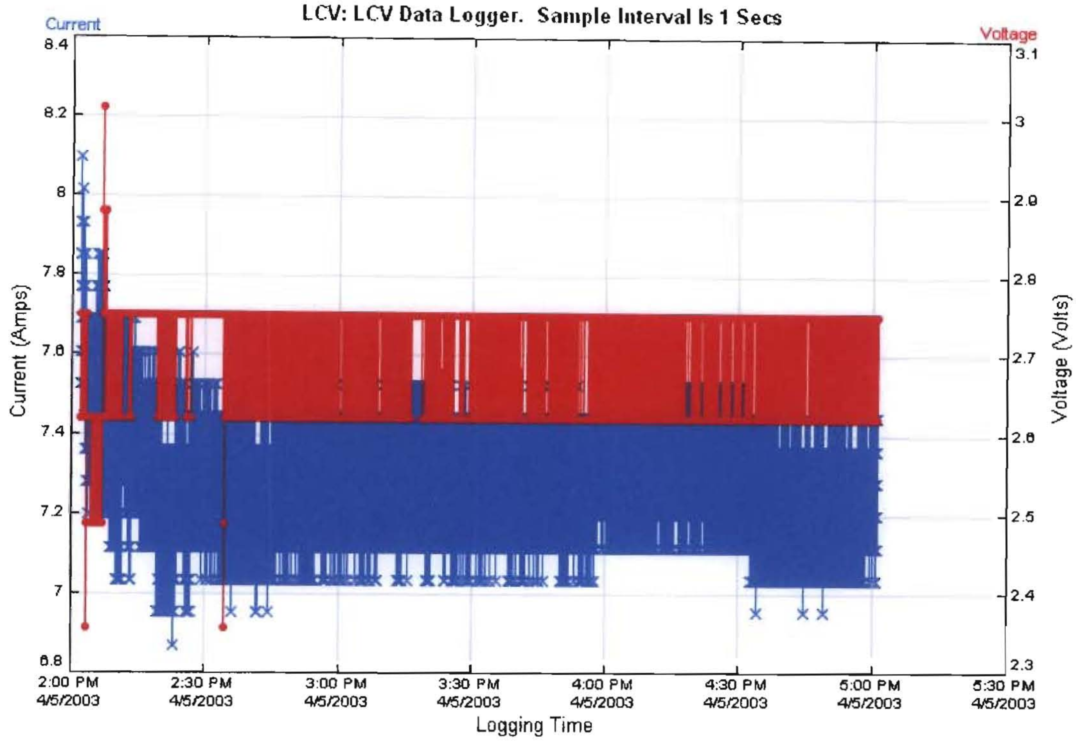


R-22 High-side
(ambient: 68 °F)

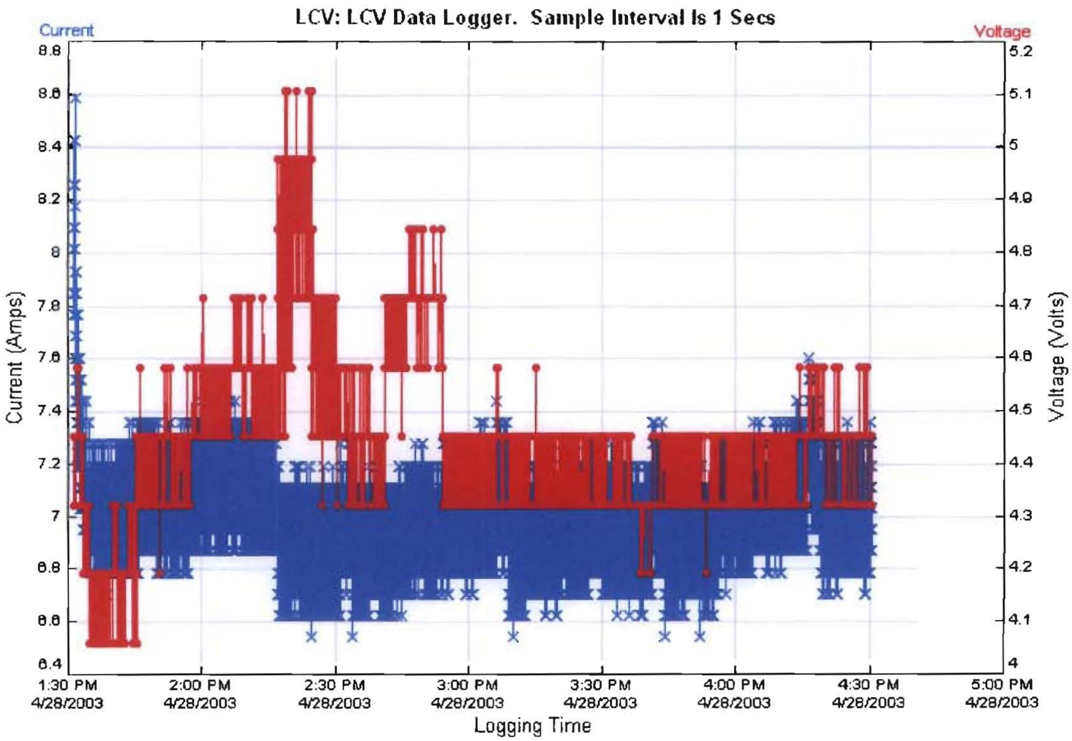


2003 R-22 & NU-22 Graphs

R-22 Amperage & Voltage

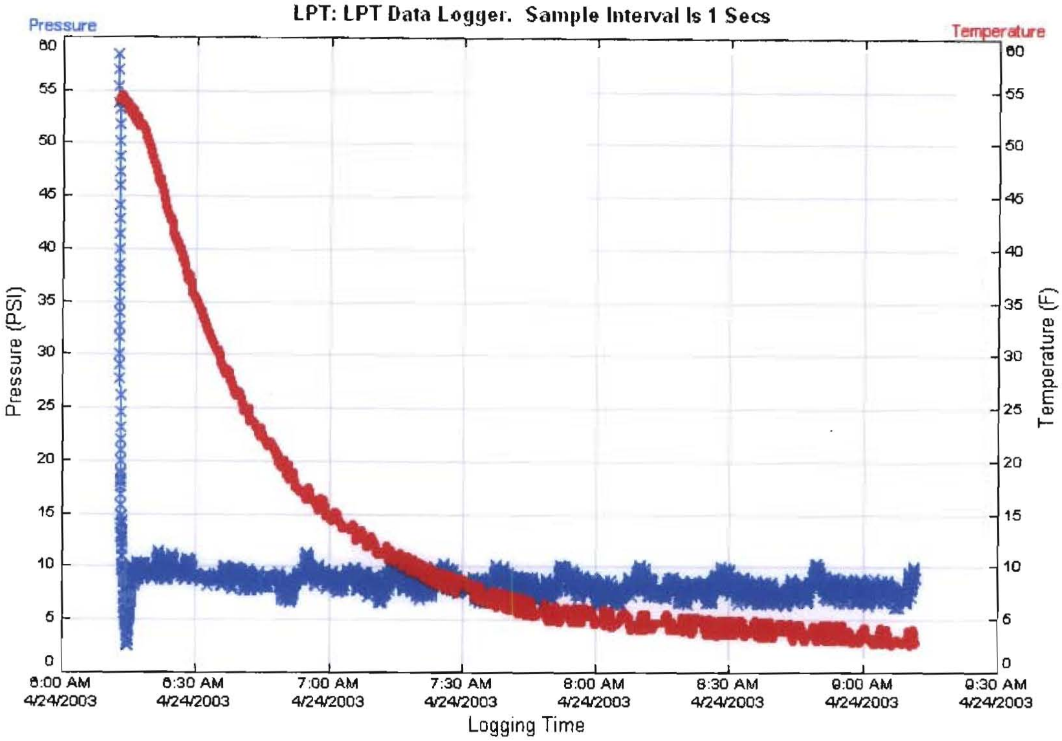


NU-22 Amperage & Voltage

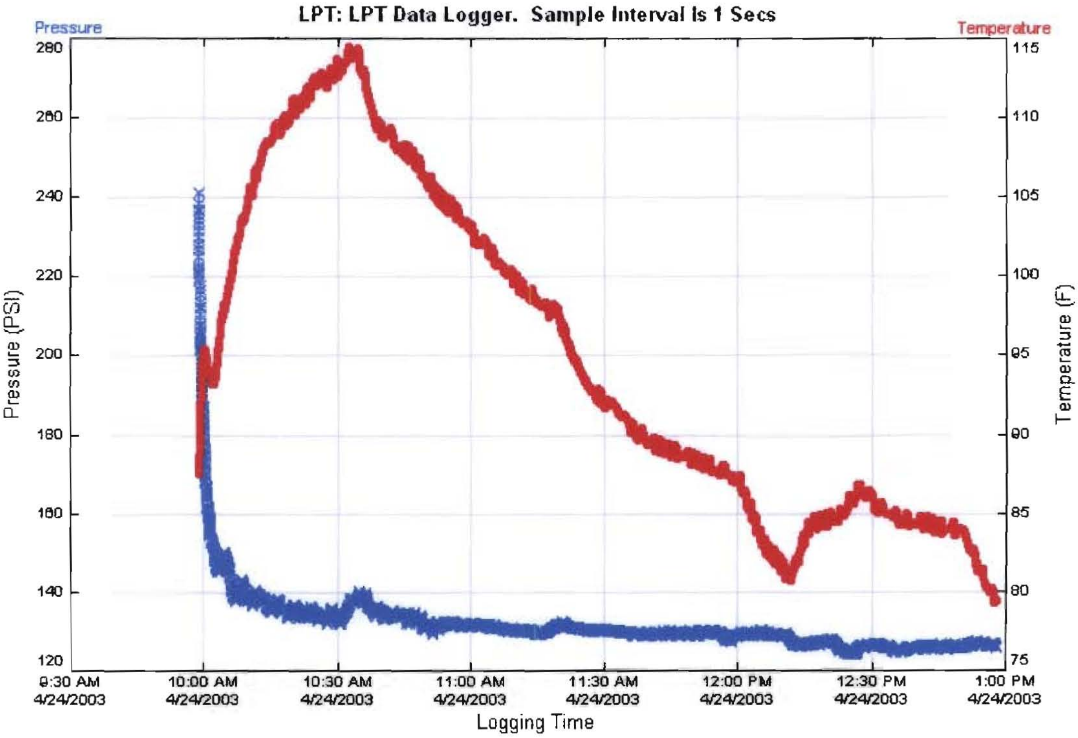


2003 R-22 & NU-22 Graphs

NU-22 Low-side
(ambient: 68 °F)

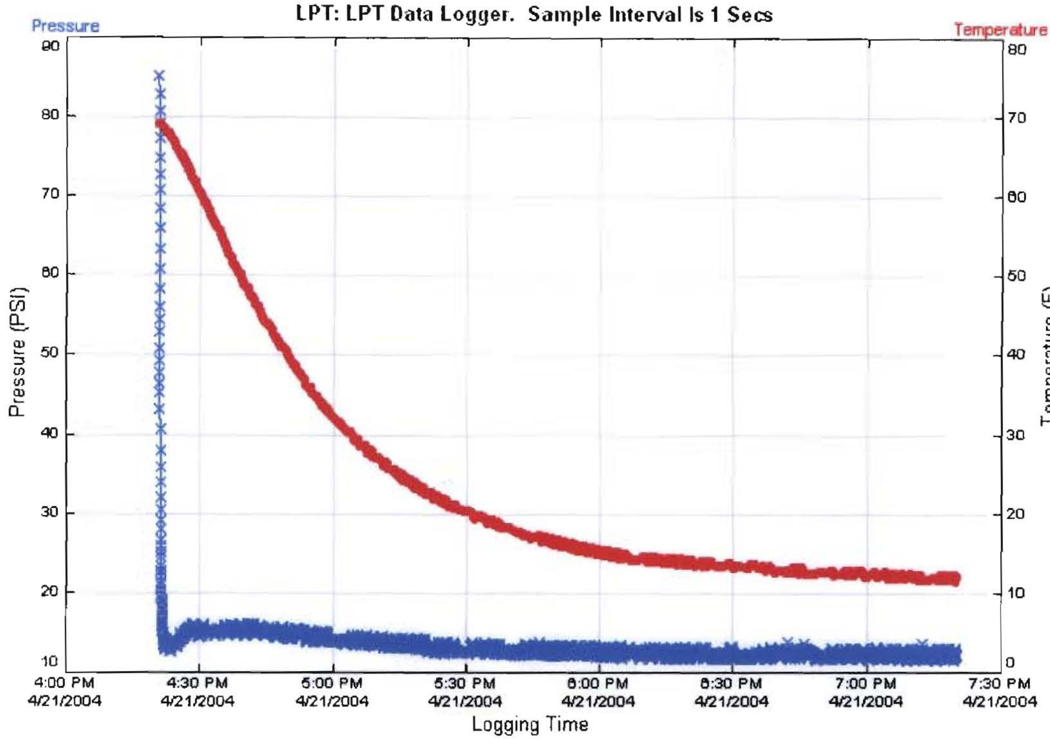


NU-22 High-side
(ambient: 68 °F)

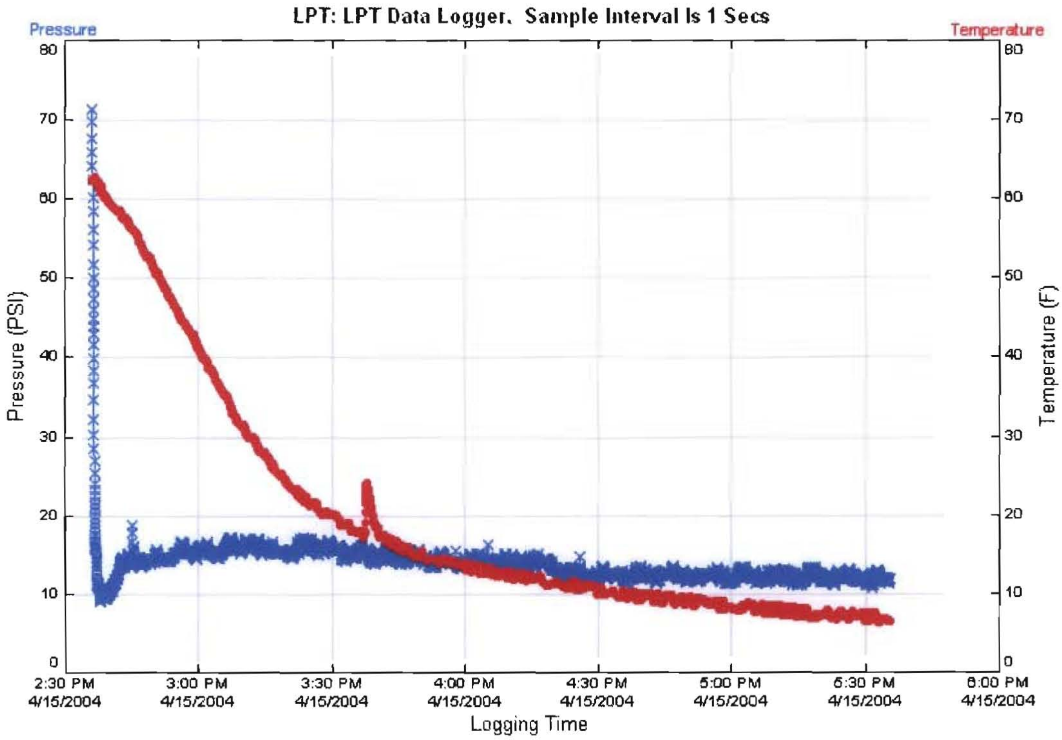


2004 NU-22 Graphs

NU-22 Low-side
(ambient: 71°F)

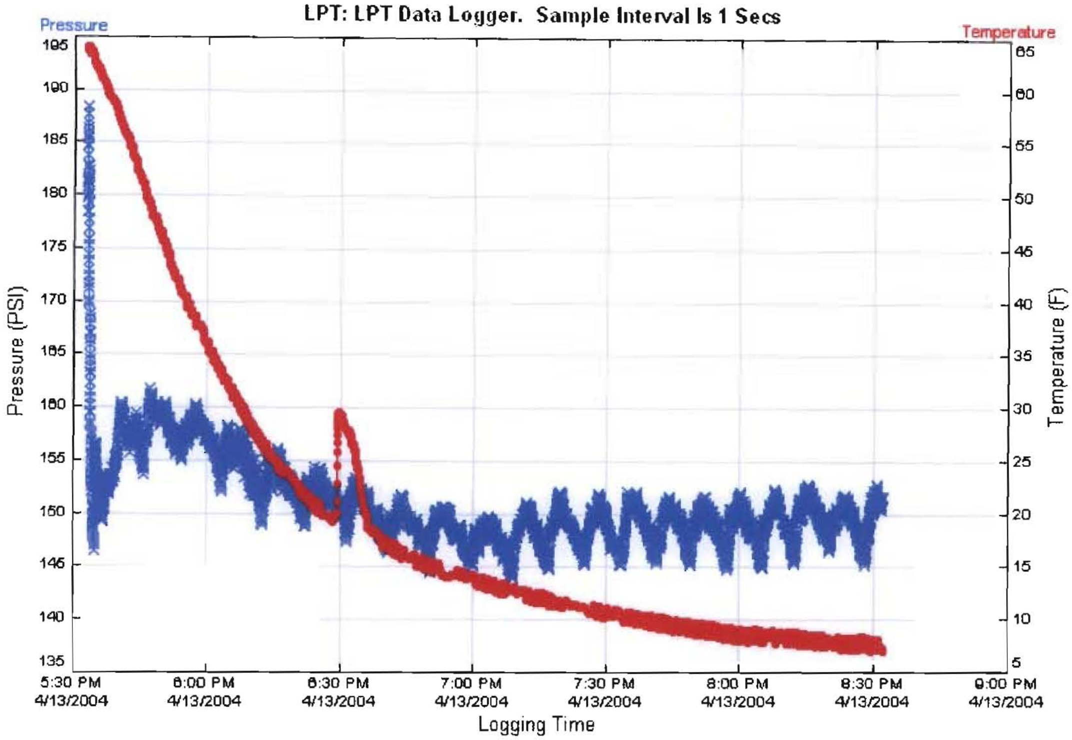


NU-22 Low-side
(ambient: 70°F)

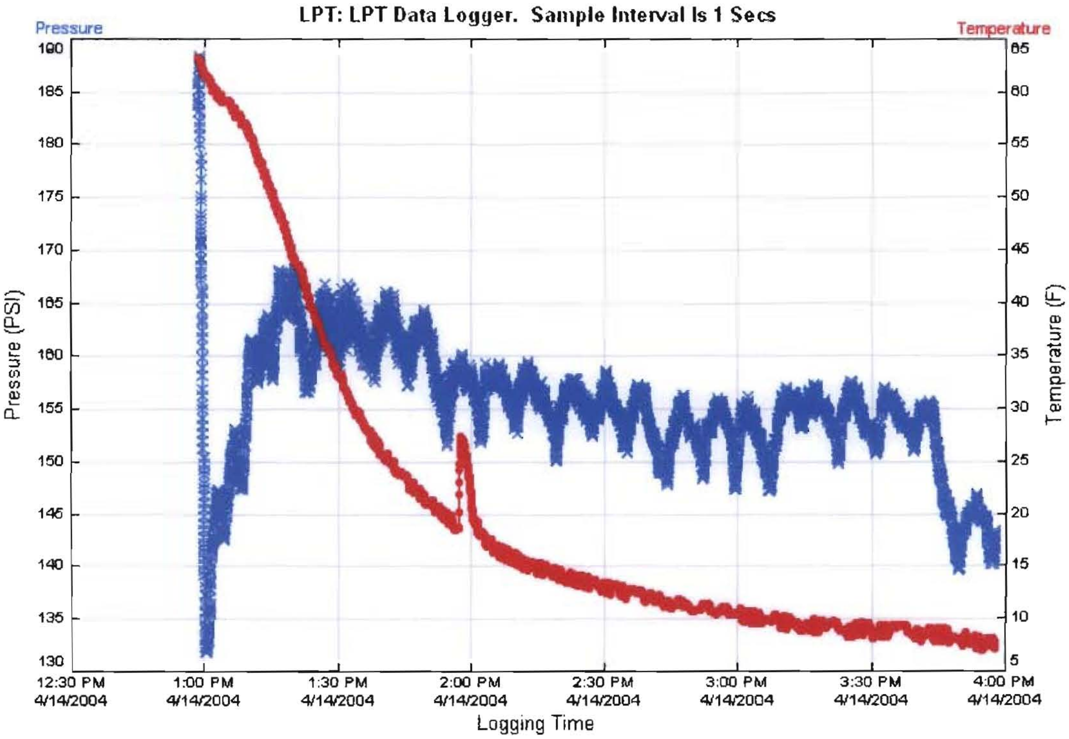


2004 NU-22 Graphs

NU-22 High-side
(ambient: 69°F)

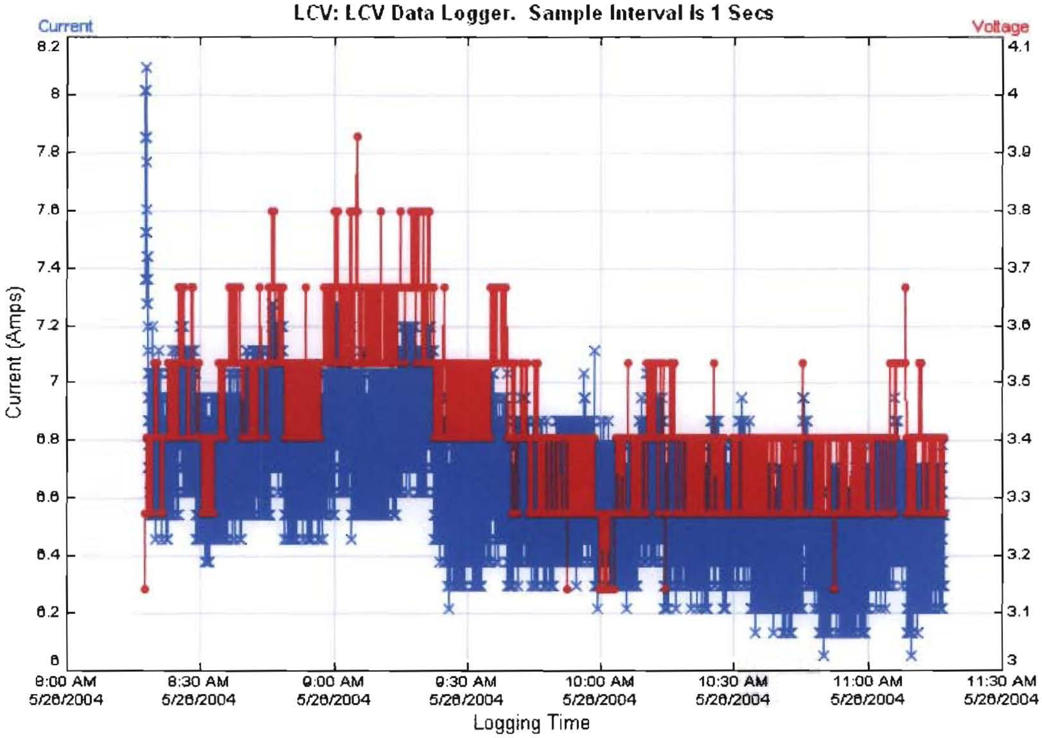


NU-22 High-side
(ambient:70°F)



2004 NU-22 Graphs

NU-22 Amperage & Voltage



Conclusion

Throughout the course of this research project the underlying purpose was to test factors claimed by the manufacturer to help determine the best plan of action for the City Ice and Cold Storage Company to embark upon. The findings of these experiments proved most useful in gauging the overall effectiveness of incorporating NU-22 into City Ice's refrigerant needs. Although the new synthetic did pass the important compatibility portion of this experiment by not damaging the equipment, other factors must be considered. The potential negatives of high pressure and energy consumption leave the chance for NU-22 to become a future problem. I found nothing in my results to support the idea that integrating NU-22 into current machinery would result in reducing energy consumption and decreasing the net cost of utilities.

My opinion of a possible explanation for the massive increase in startup pressure observed in the initial trials compared to its eventual decrease might have something to do with lubrication. When the R-22 was retrieved from the system and the NU-22 introduced, a portion of the R-22 chemical may have remained in the oil lubricant, causing the alarmingly high data. This possibility would suggest that NU-22 is not an ideal "drop in" considering that the oil would need to be replaced to completely rid the entire system of R-22. The noticeable diminishment of the observed dangerously high pressures could be caused by repetitive filtration of the refrigerant and lubricant mixture throughout the continually cycling system as a result of its extended time in the field.

With the increasing prices of R-22, the market price should be monitored in conjunction with consumption to validate whether or not NU-22 would be cheaper in the long term. For now, the price per unit of NU-22 has escalated beyond the elevating cost of R-22. From the results gathered and discussed it can be argued that NU-22 may prove to be the best synthetic blend of replacement refrigerant on the market today, but it does not match the overall quality of R-22 in its efficiency, or current cost. While perhaps being a versatile compound, if later data proves no true incompatibility issues, NU-22 is still not to be considered as a practical replacement for City Ice at this point in time. Due to the mandated conversion away from R-22 in the coming decades, a solution must be found that is both in the best interest of business and consumers as well as the environment. Due to efficiency and cost restrictions, as well as potential green house gas damage, other methods of refrigeration technique must be explored.

Scientists are continually looking for synthetic alternatives to the blended refrigerants such as NU-22 in several different avenues of research. One such method would utilize fluoroethers as the third generation of effective refrigerants. Preliminary experiments indicate that a reforming reaction using HCFC-22 can be effective in creating the potential refrigerant difluorormethylether, CH_3OCHF_2. In a model using NaCl precipitation it was found to decrease the reaction rate, while maintaining the same concentration of R-22. However, this technology is still in its infancy and poses several potential problems surrounding the addition of oxygen to the compound. Fluoroethers were found to react explosively with glass, and proved to be unstable with fibrous-glass motor materials. Although ozone friendly, some estimated Global Warming Potentials for these compounds have been reported to exceed current refrigerants by over a factor of nine.

Perhaps the most innovative and original replacement concept used in combating the problems of contemporary refrigerants contains no such form of refrigerant at all other than the inert gas helium. Thermoacoustics research began with a simple curiosity about oscillating heat transfer between gas sound waves and solid boundaries. A sound wave in a gas is usually regarded as consisting of coupled pressure and motion oscillations, but temperature oscillations are always present as well. When sound travels in small channels, oscillating heat also flows to and from the channel walls. The thermoacoustic approach begins with the assumptions that the oscillations of pressure, temperature, density, velocity, and entropy can be thought of as "small" and that they can be represented as sinusoidal functions of time.

A prototype thermoacoustic chiller has been designed, constructed and tested through the graduate program at Pennsylvania State University. The machine itself is about ten inches in diameter and nineteen inches tall, but with the cooling capacity of 119 Watts at a temperature of –24.6 °C. Its design consists of an encased insulated cylinder holding a motor, motor piston, multiplier cone, multiplier volume, and a regenerator placed in between an ambient and cold plate. The machine utilizes the inert gas helium that oscillates in and out of buffer spaces throughout the platform. The constant oscillations using the helium gas as a medium allows for heat exchange that can be used to cool a surrounding enclosed space. This relatively new technology was actually advocated greatly by Ben and Jerry's Homemade Ice Cream company in 1999 as an alternative refrigeration method to HFCs. Collaborating with Greenpeace, IEER, and other environmentally concerned organizations, Ben and Jerry helped fund the research done in 2002 at Pennsylvania State University in creating a prototype to be used in conjunction with standard ice cream cabinets. By April of 2004 the prototype was interfaced with a functioning ice cream storage cabinet with the compressor removed. This promising innovation proves to be a useful avenue for those searching for a future refrigerant solution. With no recorded detrimental effect on the ozone layer or greenhouse effect, the only problem facing this technology is the pending scarcity of natural helium supplies that are estimated to be in critical shortage within the next 25-30 years.

Many options are becoming available in current refrigerant replacement technology. At this time it would not be safe to say that NU-22 will prevail as the next leading replacement for R-22. It seems a likely candidate for many short-term goals of City Ice, but the long-term detriments cannot be predicted accurately due to the doubts raised from the research results. Throughout the course of evaluating the different forms of HCFC replacement technology, it is evident that with all of the ideas currently in place it is quite hopeful that success could become a reality in the near future. Indeed, time is of the essence, and the longer it takes to revolutionize the refrigeration industry the more the Earth's environment will continue to atrophy. With the aid of effective legislation, federally mandated annual consumption reduction, and successful enforcement of policies, the steps have been taken to ensure that a future will exist in which ozone depletion and the potential damage of global warming could diminish and perhaps eventually subside. Whether it be a new form of HFC blend similar to NU-22, fluoroether, or thermoacoustic advancement, the light at the end of the tunnel is almost in sight for keeping the refrigeration industry productive, efficient, and safe while maintaining a healthy ecosystem and global environment.

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